IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re Application No. 09/776,073	)	**For:**	**CODING SCHEME FOR A WIRELESS COMMUNICATION SYSTEM**
LING, Fuyun	)		
Examiner: VARTANIAN, Harry	)		
Filed: February 1, 2001	)	**Group No.**	**2634**

DECLARATION UNDER 37 CFR §1.131

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

We, Fuyun Ling, Nagabhushana T. Sindhushayana (Naga Bhushan), J. Rodney Walton, Mark S. Wallace and Ivan Fernandez Corbaton declare and state that:

1. We believe that we are the original and first and joint inventors of the subject matter which is claimed and for which a patent is sought in the above-identified United States patent application.

2. Prior to December 15, 2000, we conceived the idea of a coding scheme for a wireless communication system as described and claimed in our patent application identified above. We jointly participated in the preparation of a memorandum generally describing our invention. A true and correct copy of the final memorandum prepared by Fuyun Ling with the date redacted is attached hereto as Exhibit "A" to this Declaration. The dates redacted from the memorandum are prior to December 15, 2000.

3. We also jointly prepared an Information Disclosure Form "IDF," referring to the memorandum, for the purpose of disclosing our invention to our company's legal department. A true and correct copy of the IDF with the date redacted is attached hereto as Exhibit "B" to this Declaration.

4. We sent the memo and the IDF to our company's legal department on December 18, 2000.

5. Thereafter, we diligently worked with a patent attorney assigned by our company's legal department to prepare a patent application describing and claiming the subject matter set forth in the memorandum and IDF. The patent attorney forwarded to Fuyun Ling *et al.* a first draft of the patent application on January 3, 2001. A true and correct copy of the e-mail transmitting the draft patent application is attached hereto as Exhibit "C" to this declaration.

6. Upon receipt of the first draft patent application by Fuyun Ling *et al.*, we diligently performed a review and made appropriate revisions. We forwarded our revisions to our patent attorney shortly thereafter. Our patent attorney diligently revised the patent application accordingly and forwarded to us a second draft of the patent application on January 14, 2001. A true and correct copy of the e-mail transmitting the draft patent application is attached hereto as Exhibit "D" to this declaration.

7. Upon receipt of the second draft patent application by Fuyun Ling *et al.*, we diligently reviewed the application and made further revisions. We forwarded our revisions to our patent attorney shortly thereafter. Our patent attorney diligently revised the patent application accordingly and forwarded to us a third draft of the patent application on January 24, 2001. A true and correct copy of the e-mail transmitting the draft patent application is attached hereto as Exhibit "E" to this declaration.

8. Upon receipt of the third draft patent application by Fuyun Ling *et al.*, we diligently reviewed the application and made further revisions. We forwarded our revisions to our patent attorney shortly thereafter. Our patent attorney diligently revised the patent application accordingly and forwarded to us a fourth draft of the patent application on January 25, 2001. A true and correct copy of the e-mail transmitting the draft patent application is attached hereto as Exhibit "F" to this declaration.

9. Upon receipt of the fourth draft patent application by Fuyun Ling *et al.*, we diligently reviewed the application and made further revisions. We forwarded our revisions to our patent attorney shortly thereafter. Our patent attorney diligently revised the patent application accordingly and forwarded to us a fifth draft of the patent application on January 26, 2001. A true and correct copy of the e-mail transmitting the draft patent application is attached hereto as Exhibit "G" to this declaration.

10. We then began our final review of the revised patent application to ensure that the full breadth of our inventive concepts were adequately described and claimed. Once the patent application was revised, we advised the patent attorney to file the revised patent application.

11. On February 1, 2001, the final patent application was filed with the U.S. Patent and Trademark Office.

12. We further declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of Title 18 of the United States Code and that such willful false statement may jeopardize the validity of the application or any patent issuing thereon.

1/26/2005
Date

Fuyun Ling

1-26-2005
Date

Nagabhushana T. Sindhushayana
(Naga Bhushan)

1/24/05
Date

J. Rodney Walton

1/25/05
Date

Mark S. Wallace

1/25/05
Date

Ivan Fernandez Corbaton

Truong Dinh

From: Truong Dinh [tdinh@dinhlaw.com]
Sent: Sunday, January 14, 2001 7:42 PM
To: fling@qualoomm.com; rwalton@qualcomm.com
Cc: steph@qualoomm.com; tdinh@dinhlaw.com
Subject: second draft of BTC-GM for OFDM patent application

104-37 app v2.doc 104-37 figs.doc

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ATTORNEY-CLIENT PRIVILEGED

Hi Fuyun and Rod,

Attached is the second draft of the "BTC-GM for OFDM" patent application. The text and figs are password protected. Fuyun, could you forward this draft to Mark Wallace and Ivan for review. I don't have their email addresses.

I've made changes to the application to incorporate Fuyun's comments.

Please review this second draft and provide any additional comments/corrections. Please let me know if you should have any questions.

Best regards,
Truong

PS - Steph, I don't have the disclosure number for this one. Could you forward me that info.

Truong Dinh

From: Truong Dinh [tdinh@dinhlaw.com]
Sent: Thursday, January 25, 2001 4:19 PM
To: fling@qualcomm.com; rwalton@qualcomm.com
Cc: Truong Dinh
Subject: Third draft of BTC-GM for OFDM patent application

104-37 app v4.doc

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ATTORNEY-CLIENT PRIVILEGED

Hi Fuyun and Rod,

Attached is the fourth draft of the "BTC-GM for OFDM" patent application.

I revised the application to address Rod's latest comments (attached below).

Please review this fourth draft and provide any additional comments/corrections.

Best regards,
Truong

-----Original Message-----
From: Rod Walton [mailto:rwalton@qualcomm.com]
Sent: Thursday, January 25, 2001 8:35 AM
To: Truong Dinh
Cc: fling@qualcomm.com
Subject: Re: Third draft of BTC-GM for OFDM patent application

Hi Truong:

Please call when you get in,

Rod (978-318-0649)

Binary Turbo Codes with Gray Mapping for OFDM and OFDM with MIMO Communication Systems

Fuyun Ling

1. Introduction

In a communication system using orthogonal frequency division modulation (OFDM), the transmission symbols (Tx symbols) are modulated on different subcarriers, called frequency bins. Since Tx symbols sent over different subcarriers experience different signal to noise ratio conditions, the number of bits per symbol can be sent with an acceptable error rate, are different for different subcarriers.

In an OFDM communication system with multiple transmitting and receiving antennas (i.e., multiple input/multiple output, or MIMO), the communication channel of each frequency bin can be further decomposed into multiple independent subchannels. The number of such subchannels is less than or equal to the lesser one of the number of the transmitting and the number of receiving antennas. Each of such subchannels is also called an eigen-mode if these subchannels are independent of each other. A Tx symbol can be sent over each of the eigen-modes in each frequency bin. Since the SNRs are different for each eigen modes, the number of bits can be sent over each eigen-mode is also different.

Due to the non-uniform nature of the Tx symbols over different frequency bins and eigen modes, which may be different for different system set-up and may vary with time, a powerful yet flexible coding scheme is needed for the OFDM communication systems with or without MIMO.

In recent years, Turbo code has been as the choice of error-correction coding method due to its near-optimal performance and moderate complexity. The binary form of the Turbo codes has been investigated relatively thoroughly and better understood. Such Turbo codes can be straightforwardly used when the Tx symbols are BPSK or QPSK modulated. When considering applications under high-SNR environment, which the OFDM schemes usually targeted, high-order modulations, such as 8PSK, 16QAM and 64 QAM, become necessary to increase the bandwidth efficiency.

Even though Turbo trellis coded modulation (TTCM) schemes has been considered previously by a number of researchers. A simple alternative approach is to use punctured binary turbo codes and Gray mapping for high-order modulation. As it was shown in [1], somewhat surprisingly, the latter simple scheme can achieve a performance quite close to the more optimal TTCM while provides a high degree of flexibility. Its performance is very robust under different puncture parameters. Thus, the punctured binary turbo codes

mapped to high-order modulation through Gray mapping is a good candidate for channel coding in OFDM and OFDM with MIMO systems.

2. Description

Basics of Punctured Turbo Codes with Gray Mapping

As shown in [1] *binary turbo code with Gray mapping* (BTC-GM) uses conventional binary turbo codes directly, and map the coded binary symbols onto a high-order constellation after these coded symbols being punctured to proper coding rate. A reasonable choice for the mapping is the Gray mapping. The diagram of such an encoding scheme is shown in Figure 1. We call such a scheme *binary turbo code with the Gray mapping* (BTC-GM). The encoding procedure is essentially the same as in CDMA2000 except the last step, where several binary symbols are grouped as a non-binary symbol and mapped onto a high-order constellation. Note that the mapping is carried out after the channel interleaving. Here the channel interleaver serves an additional role. It ensures that the binary symbols, which form a single non-binary symbol, are not close to each other at the output of the binary encoder. It was found, however, for static AWGN channels, such channel interleaver is less critical than for non-Turbo coded schemes due to the existence of the code interleaver.

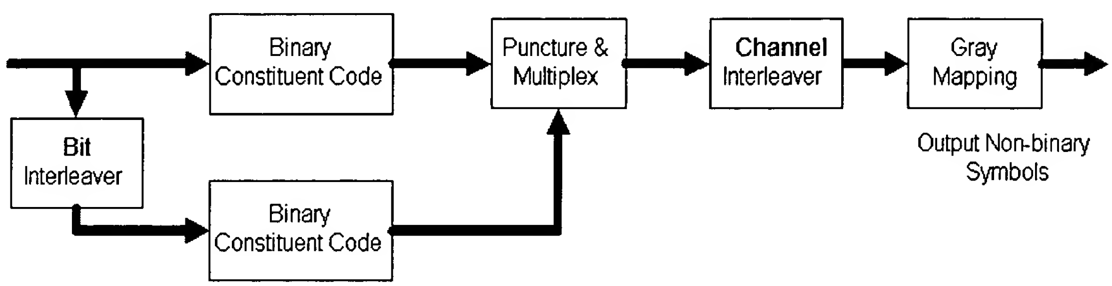

Figure 1. Coding scheme using binary turbo code with the Gray mapping.

To achieve high bandwidth efficiency for high order modulation, the punctured binary Turbo code has a relatively high rate, e.g., r = 5/6. Even though such a high rate binary code is known to require a higher E_b/N_0 than that for a lower rate binary codes, Such high rate binary codes with Gray mapping yield satisfactory performance for bandwidth efficiency coding and modulation. As shown in [1] the performance is about or less than 1.5 dB from the capacity bound for the corresponding modulation symbols.

For BTC-GM schemes that we investigated, the high rate binary Turbo code is generated by simply puncturing the non-systematic bits of the rate 1/3 Turbo code as described in the cdma2000 standard. It was found that the performance of the BTC-GM is insensitive to the specific puncturing pattern. Only two rules are used in the design the puncturer: (1) the number of bits punctured should be balanced between the two constituent codes; (2) the remaining bits should be distributed relatively evenly over the coded block. In our implementation, we arrange the parity bits from the two constituent encoders as two linear array in the order that it is generated. The remaining bits are selected from each of the arrays as uniformly as possible. The remaining parity bits and

the systematic bits are then combined in to a single bit stream, interleaved, grouped and Gray-mapped into the high order modulation symbols.

Based on the above encoding scheme, a decoder can be implemented as in Figure 2. First, the log-likelihood ratios (LLR) of the binary symbols are calculated from the received signals. The binary symbol LLR's are de-interleaved and then fed into a binary turbo decoding algorithm. The remaining decoding algorithm is exactly the same as used for conventional binary Turbo decoders.

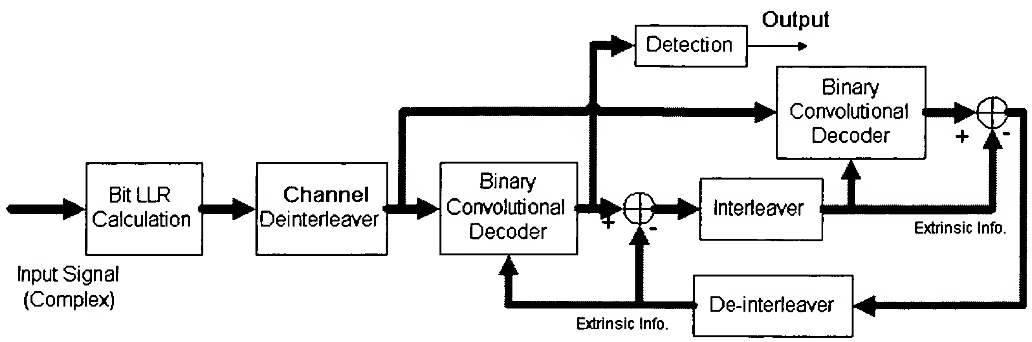

Figure 2. Decoding scheme using binary turbo code with the Gray mapping.

BTC-GM for OFDM and OFDM with MIMO

As stated above, one Tx symbol is transmitted over a frequency bin/eigen-mode. Each of such frequency-bin/eigen-mode as an SNR that is know to both transmitter and receiver. The modulation and coding parameters of the Tx symbol are determined by the SNR of the corresponding frequency-bin/eigen-mode. Below we discuss two of methods that determine the modulation/coding parameters for BTC-GM in the OFDM and OFDM with MIMO communication systems.

Both methods start with determining the modulation symbol to be used for each bin/mode by table look-up. The look-up table is generated from BTC-GM simulation as shown in [1]. One example of such a table is given in Table 1.

Table one the required Eb/No range for < 1% FER

SNR range	# of info. bits/symbol	Modulation Symbol	# of coded. bits/symbol	Coding rate
1.2 – 4.4	1	QPSK	2	1/2
4.4 – 6.4	1.5	QPSK	2	3/4
6.4 – 8.35	2	16QAM	4	1/2
8.35 – 10.4	2.5	16QAM	4	5/8
10.4 – 12.3	3	16QAM	4	3/4

12.3 – 14.15	3.5	64QAM	6	7/12
14.15 – 15.55	4	64QAM	6	2/3
15.55 – 27.35	4.5	64QAM	6	3/4
> 17.35	5	64QAM	6	5/6

The first methods uses a BTC code with a single coding rate over all bins/modes. The procedure to determine the modulation/coding parameters is as follows.

(1) Determine the modulation symbol constellation for each bin/mode based on its SNR.

(2) Compute the number of total coded bits (systematic + parity bits + tail bits) based on the result from (1).

(3) Determine the number of systematic bits (including information + systematic tail bits) for each bin/mode based on the SNR of that bin/mode.

(4) Compute the number of total systematic bits by summing what calculated above.

(5) Use 1/3 BTC to code the systematic bits. (Assume the required coding rate is greater than 1/3.

(6) Puncture the parity bits to the required number of all coded bits (systematic + parity bits + tail bits).

(7) Gray map the coded bits to the symbols determined in (1) and send these symbols over corresponding bins/modes.

The above approach is relatively simple to implement. The problem is that if the distribution of the SNRs is widespread, the distance between the constellation points relative to the noise variance in different constellation will very widely. This may impact the performance. Below we show another method to improve the normalized distance.

The second methods uses a BTC code with variable puncturing rate over bins/modes with different SNR. The procedure to determine the modulation/coding parameters is as follows.

(1) Determine the number of systematic (including information + systematic portion of tail) bits to be transmitted for each bin/mode based on its SNR. The computation is based on a table similar to Table 1 above but can have more quantization levels. The modulation symbol constellation is determined based on the number of bits per symbol.

(2) Group the bins/modes into multiple segments such that these bins/modes in a segment support the same number of systematic bits.

(3) Compute the number of the total systematic bits and total parity bits that can be transmitted in each segment, e. g., in segment i there are K_i bins/modes, each of which can support N_i systematic bits and P_i parity bits. Compute the number of total systematic bits according to $\sum_i K_i N_i$

(4) Use 1/3 BTC to code the systematic bits computed above. (Assume the required coding rate is greater than 1/3).

(5) Assign $3N_i$ (interleaved) coded bits ($2N_i$ parity bits and N_i systematic bits) to the i-th segment.

(6) Puncture the $2N_i$ parity bits to yield P_i parity bits to be transmitted.

(7) Gray map the (N_i+P_i) coded bits to the K_i symbols determined in (2) and assign these symbols to corresponding bins/modes for transmission.

By using this approach, the number of bits required to be sent over each bin/mode needed to be communicated from the receiver to the transmitter. The quantization granularity can be finer because it has a quantization level of one bit over the segment of N_i systematic bits.

The granularity can be further reduced if we can carry over the quantization from segment to segment. Namely, in the case we need to round-off one bit in one segment, we may round-up one bit in the next segment if appropriate.

<u>A Method of Flexible Punctured (or Retaining) Parity Bits</u>

To implement the BTC-GM for OFDM and OFDM with MIMO communication systems, it is necessary to have a flexible puncturing scheme to generate the necessary number of parity bits in each segment. Since the coding rate is usually, higher than 1/2, it may be easier to implement the puncturing by retaining a required number of bits. For example, if we have 20 16QAM symbols in a segment and the SNR allows to transmit 2.75 bits per symbol, there will be 55 systematic bits and 35 parity bits in this segment. Thus, we need to puncture the 110 parity bits to 35. We can use the following method to achieve retaining P out of Q parity bits as follows.

We construct a first counter which will wrap around after it content reaches beyond Q-1 (modulo Q operation). There will be a second counter counting the Q parity bits. Both counters are always set to zero initially. In the Q parity bits, the first bit is always to be retained. Then the counting starts by incrementing the first counter by P and the second counter by 1. If the first counter experience a modulo operating, the bit corresponding to the content of the second counter will be retained. This process continues until all of the Q bits are exhausted. A similar approach has been proposed and accepted in principle in 3GPP2 AMR flexible rate generation [2].

3. Framing Considerations

It is probably natural to consider one or a integer multiple of OFDM symbol as a physical frame. However, due to varying coding rate from one bin/mode to next, the number of information bits per such a physical frame will vary from transmission to transmission in fine steps. Thus, it may be difficult to tie such physical frames to data packets, or logical frames, which are preferably to have a small number of sizes of information bits. One possibility to solve this problem is to make the logical frame (data packets) to be independent of OFDM symbols. Namely, coding is performed over data packets. The coded bits of these packets are grouped together then mapped to OFDM symbols. Thus, a data packet can span more than one OFDM symbol and can cross the OFDM symbol boundaries. Consequently, each OFDM symbol can contained the coded bits from multiple data packets.

References:

[1] Yongbin Wei and Fuyun Ling, "Binary Turbo Codes with Gray Mapped High-Order Modulation," Qualcomm internal memo, June 2000.

[2] "Method and Apparatus for Puncturing Code Symbols in a Communication System," Qualcomm Patent Application Ref. No PA000334, Nov.(?) 2000.

QUALCOMM INCORPORATED
INVENTION DISCLOSURE

ID NO.: __________

The invention herein described was evolved during the course of my employment and is being submitted pursuant to the terms of the Employee Agreement signed by me.

1. TITLE OF INVENTION: Binary Turbo Codes with Gray Mapping for OFDM and OFDM with MIMO Communication Systems

2. PURPOSE OF INVENTION: To provide a coding method that achieves near channel capacity in Communication systems employing OFDM or OFDM with Multiple Transmitter and Receiver Antennas, which is also simple to implement.

3. CONCEPTION:
   Invention conceived on: __________
   This disclosure written on: __________

4. REDUCTION TO PRACTICE, if any:
   Construction of device started on: N. A. .
   Device completed on : N. A..
   Device tested on : N. A..

5. BRIEF DESCRIPTION: See Attached .

Incorporated herein and forming a part of this disclosure are the following:

Additional Sheets (No.) Papers (No.) Photographs (No.) Prints (No.)

6. Indicate whether invention conceived or reduced to practice under:

   (a) Government or other contract? Yes__ No_X_ if yes,

      (I) Project Name: (Insert Project Name Here) .

      (II) Account Charged: (Insert Account Charged Here) .

   (b) Company funded? Yes_X_ No__if yes,

      (I) Project Name: New License Bands (MMDS, LMDS, WLAN) .

      (II) Account Charged: 70694-02 .

7. IDENTIFY ANY ANTICIPATED OR PAST PUBLICATIONS, OFFERS FOR SALE, REPORTS, PROPOSALS, OR OTHER TYPE OF DISCLOSURE WHETHER WRITTEN OR ORAL THAT WILL BE MADE OUTSIDE OF THE COMPANY.

N. A .

8. INVENTOR(s):

Inventor Signature	Inventor Printed Name	Date
	Fuyun Ling	
	Rod Walton	
	Mark Wallace	
	Ivan Fernandez	
	(Rod: Anyone else?)	

9. WITNESSES:

The invention was disclosed to me by the above inventor(s).

The description was examined and is clearly understood.

Witness Signature	Witness Printed Name	Date

Witness Signature	Witness Printed Name	Date

Truong Dinh

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Cc: steph@qualcomm.com; tdinh@dinhlaw.com
Subject: First draft of Binary Turbo Code with Gray Mapping (BTC-GM) for OFDM patent application

104-37 app.doc 104-37 figs.doc

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ATTORNEY-CLIENT PRIVILEGED

Hi Fuyun and Bhushan,

Attached is the first draft of the BTC-GM for OFDM patent application. The text and figures are both protected with a password. I will call and let you know.

Please review the application carefully and make any comments, suggestions or changes deemed necessary or appropriate. Also, please provide any additional implementation details which may not have been covered. After your review, please send me your comments and corrections so that I can make the necessary changes to the application. A revised draft will then be sent to you for review.

Please let me know if you should have any questions or comments.

Best regards,
Truong

Truong Dinh

From: Truong Dinh [tdinh@dinhlaw.com]
Sent: Wednesday, January 24, 2001 11:00 PM
To: fling@qualcomm.com; rwalton@qualcomm.com
Cc: Truong Dinh
Subject: Third draft of BTC-GM for OFDM patent application

104-37 app v3.doc

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ATTORNEY-CLIENT PRIVILEGED

Hi Fuyun and Rod,

Attached is the third draft of the "BTC-GM for OFDM" patent application.

I made the following changes:

Please review this third draft and provide any additional comments/corrections. Please let me know if you should have any questions.

Best regards,
Truong

Truong Dinh

From: Truong Dinh [tdinh@dinhlaw.com]
Sent: Friday, January 26, 2001 10:41 AM
To: fling@qualcomm.com; rwalton@qualcomm.com
Cc: Truong Dinh
Subject: Fifth draft of BTC-GM for OFDM patent application

104-37 app v5.doc

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ATTORNEY-CLIENT PRIVILEGED

Hi Fuyun and Rod,

Attached is the fifth draft of the "BTC-GM for OFDM" patent application.

Please review this draft and provide any additional comments/corrections. Thank you for your diligence in reviewing this application. I think we should be very close.

Best regards,
Truong